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**Tool for Human-Systems Integration Assessment:
HSI Scorecard**

Abstract

This paper describes the development and rationale for a human-systems integration (HSI) scorecard that can be used in reviews of vehicle specification and design. This tool can be used to assess whether specific HSI related criteria have been met as part of a project milestone or critical event, such as technical reviews, crew station reviews, mockup evaluations, or even review of major plans or processes. Examples of HSI related criteria include Human Performance Capabilities, Health Management, Human System Interfaces, Anthropometry and Biomechanics, and Natural and Induced Environments. The tool is not intended to evaluate requirements compliance and verification, but to review how well the human related systems have been considered for the specific event and to identify gaps and vulnerabilities from an HSI perspective.

The scorecard offers common basis, and criteria for discussions among system managers, evaluators, and design engineers. Furthermore, the scorecard items highlight the main areas of system development that need to be followed during system lifecycle. The ratings provide a repeatable quantitative measure to what has been often seen as only subjective commentary. Thus, the scorecard is anticipated to be a useful HSI tool to communicate review results to the institutional and the project office management.

Introduction

Human-Systems Integration (HSI) emphasizes human considerations in systems design to optimize the fully integrated system's (i.e., human and machine's) performance and to reduce lifecycle costs. HSI at NASA is a multidisciplinary field of study composed of several user-related areas, including: Human Factors Engineering, System Safety, Health Hazards, Manpower & Personnel, Training, and Habitability.

The incorporation and practice of HSI within NASA is not mandated and therefore is not always included in programs and projects most effectively. Development of a clearly defined, disciplined, unified, and repeatable HSI process would help ensure that the knowledge benefits the appropriate programs/projects. A well-developed HSI process would also include standardized HSI tools that support the implementation of the process. Proper tools can help capture HSI information from system and sub-system managers in a consistent way and they can help track system development.

Several HSI tools have been developed in the area of military service acquisition for manpower, personnel and training integration. Among others, the U.S. Army uses the Improved Performance Research Integration Tool (IMPRINT) to describe and analyze task networks and to predict the probability of success. Another example, the U.S. Navy's Systems Engineering Analysis Integration Tool (SEAIT) evaluates the effect of manpower on ship design, performance and cost (Booher, 2003, Pew & Mavor, 2007).

The use of HSI tools shortens design time, increase productivity, and lower development costs by facilitating human-centered design with early consideration/inclusion of human capabilities and limitations in the design. NASA needed a tool that

encompasses all the areas on HSI and can be used at system reviews giving a common basis for evaluations and providing an overall picture of the HSI domains. NASA HSI team recognized the significance of systematic and quantitative approach to assess the level of design maturity and quality of HSI in the spacecraft design and development. Thus, the HSI scorecard has been developed for this purpose.

Background of the HSI Scorecard

NASA has recently revised the Human Rating Requirements and Guidelines for Space Flight Systems (HRR) containing requirements and guidelines for certifying the design of all the agency space vehicles carrying humans. In order to facilitate the human rating certification, that is, to confirm that the vehicle can fly humans safely, and to ensure human-centered design, the Constellation Program also developed the Human Systems Integration Requirements (HSIR) that drives the design of space vehicles, their systems and equipment with which humans interface in the Constellation vehicles like the Orion Crew Exploration Vehicle. These requirements ensure that the design of Constellation vehicles is centered on the needs, capabilities and limitations of the human.

The HSI scorecard under development is loosely based on the HRR and HSIR. It contains broad areas such as HSI Process, Human Systems Interfaces, and Human Performance Capabilities, among others. Each general area contains one or more sub categories, such as design team composition under HSI Process. All these are rated based on how well expectations (1 - unsatisfactory to 5 – exceptional) were met at a particular event, such as a technical review of a specific feature, or an integrated cockpit layout evaluation. This type of rating allows for assigning a score in each area, as well as obtaining an overall score for a system.

The HSI scorecard is intended to be used at technical reviews of specification documentation and design, preliminary design review, detailed design review and other reviews that are conducted by a system engineer, a system manager or a human factors engineer concerned with human health and performance. The scorecard can be broken up into sections and the individual sections can be used by subject matter experts. For example, environmental factors can be evaluated by a toxicologist or a lighting specialist. Similarly, the human systems interface rating may be conducted by a human factors engineer.

Beyond designing a system according to requirements, there is also a need to evaluate a system based on how well the HSI process has been followed and how well HSI guidelines have been implemented. The system can also be evaluated more in-depth, such as whether or not sensory capabilities of humans were considered in the design process.

Overall, the HSI scorecard can provide a more complete picture about the progress of system design at different phases of the lifecycle. This will be a useful HSI tool for systems engineers as well as to human factors engineers and other specialists to communicate the acceptability of the HSI aspect of the design in support of human rating and certification.

Motivation for the HSI scorecard

The HSI scorecard is a tool for assessing whether or not specific HSI related criteria have been met as part of a project milestone, event or product. The intent of the

tool is not to look line by line at whether or not requirements have been used at the right level, and whether they have been verified, but to review how well the human as a system has been considered for the specific event/product and to identify major gaps and vulnerabilities from an HSI perspective at different design and development phases. Although the review may be subjective, this scorecard attempts to provide rigor, or quantitative measure to the subjective commentary.

The scorecard tool is intended to provide a high level snapshot that can be presented by an HSI lead to the Health and Medical Technical Authority (HMTA) and Institutional Management of Space Life Sciences Directorate (SLSD) for concurrence as well as to the Project Management team to give an overall summary of the state of the human system requirements incorporation for a particular event/product. In addition, this data will help independent assessment of the vehicle by the SLSD team to obtain SLSD/HMTA approval of the Constellation vehicle. The results of the assessments would capture evidence for human rating the vehicle and provide Program Office personnel the issues or vulnerabilities from a human system perspective.

Detailed description of the HSI Scorecard

During the lifecycle of the system several reviews are conducted at different stages to assess the design and development process. Such events could include system baseline review, preliminary design review, critical design review, technical reviews, crew station reviews, mockup evaluations, table top reviews, cockpit working group assessments, and review of major plans or processes. The products from these reviews include system/subsystem specifications or data books, analysis reports, and engineering drawings. However, in general, these reviews do not necessarily provide a full picture of how and whether the HSI process has been implemented during the phases.

The items in the scorecard are rated on a scale from 1 to 5 based on whether they meet the expectations for the current phase of the system (e.g., pre-PDR, PDR) or not. If a system is expected to have a 10% maturity level being at the beginning of the design phase, it can still be rated 5 (exceptional) on the rating scale if all expectations have been exceeded for that maturity level.

The rating scales also provide the option not to rate an item in case it is not relevant to the review or system. Furthermore, each item has a section for comments to identify major pros/cons and vulnerabilities for that item. General comments may be added at the end of the form. The scorecard also tracks system and subsystem name, type of review, maturity expectation, and design phase along with reviewer information and date.

Areas in the HSI scorecard

Based on the topics covered in HSIR, there are 10 areas included in the scorecard: HSI process, human system interfaces, anthropometry and biomechanics, human performance capabilities, natural and induced environments, crew safety, health management, architecture, hardware and equipment, information management.

The HSI process area refers to the involvement of human system, human design and HSI human factors personnel in the design process. The human interfaces area has items referring to how well interfaces are designed with the human as a system in mind, including use of task analysis, human centered design practices, and human-in-the-loop testing. There are items on anthropometrics and biomechanics focusing on how well

human physical characteristics are considered in the design, such as strength and accessibility, and reach analysis and crew population/size.

In the human performance capabilities section the items are concerned with considerations of human performance and sensory capabilities, such as gravity (G) condition, and physical/mental workload in cases where human response is required as system input. Items referring to considerations of atmospheric conditions, acoustics, temperature, vibration, radiation, and lighting are in the natural and induced environments section. The health management area refers to the human system design considerations to include management of crew health in areas such as nominal/contingency landing, crew survivability, nourishment, exercise, health monitoring, communication, and rest. Crew safety has a section as well as system architecture that is addressed in terms of habitable volume analysis, ability to perform required tasks. Finally, there is a section on hardware usability and maintainability as well as information management.

Development of the HSI Scorecard

The first version of the HSI scorecard was developed based on the main categories that are used to organize information in HSIR. Items were added based on importance and generality with summarizing requirement language. Based on discussions with HSI and systems engineers, the scale used from 0 to 100 in 25% increments to indicate to what percent expectations have been met. After several iterations, the scale was changed to a simple Likert scale to make it easier to understand for raters. The scale goes from 1 - unsatisfactory to 5 – exceptional (see Figure 1).

The scorecard has been used in several reviews for Orion, Crew Exploration Vehicle (CEV) and it was revised based on comments received from these reviews. The description of the items has been changed to make it more appropriate for the users. Items were added or removed depending on their relevance. For example, all HSIR topics related to extravehicular activity (EVA) and ground operations were removed. These may be added back to an EVA centered version of the scorecard.

Please insert Figure 1 about here

Moreover, we conducted in-depth interviews with users to get feedback on the scorecard. Most reviewers used the scorecard three or more times at technical reviews. In general, the electronic version was preferred to the paper version; however, the paper version was also deemed necessary to provide flexibility when using a computer is not feasible. Users think the scorecard provided a broader picture for the review and a high level overview that otherwise would not be available. In addition, they reported that the tool helped them to be consistent in their assessments of different systems/sub-systems.

Reviewers reported that filling out the scorecard takes a fair amount of time. This may not be a disadvantage from the point of view of the HSI lead because it makes sure that the review thorough, especially since this data will help to determine if the vehicle design is human-rated for a space flight.

Reporting with the HSI Scorecard

One purpose of the scorecard is to provide a concise report to program managers about the development status of a system. Depending of the details needed, scores or scores averaged for each area along with comments may be reported. For one review, the result may be summarized in a figure (see Figure 2) showing the mean ratings for each area. This kind of visualization helps with finding at a glance the areas that perform below expectation and areas that are doing as expected.

Please insert Figure 2 about here

For a series of reviews the results may be shown as a figure and or table (Figure 3 and Table 1). Summarizing several reviews in one figure or table provides a picture of system development process in time. Areas that have changed dramatically over time can be easily pointed out; these may be the areas that need more attention in the next lifecycle.

Please insert Table 1 about here

Please insert Figure 3 about here

Benefits of the HSI Scorecard

During the development process and evaluations, the scorecard proved to be beneficial in several respects, beyond providing consistent ratings of systems.

- a) Negotiation tool. The scorecard offers common language, basis, and criteria for discussions among system managers, evaluators, and design engineers. Due to this, the scorecard can be used as a negotiation tool in reviews and help early/critical inclusion of the project prime contractor's human factors/ HSI personnel in the design and development efforts and their products.
- b) Look-ahead tool. The scorecard items highlight the main areas of system development that need to be followed during system lifecycle. The scorecard specifies common issues on a high level that helps focus on all areas of development.
- c) Repeatability. The ratings, even though they are subjective, provide a repeatable quantitative measure. As reviewers get more familiar with the scorecard, the ratings will be easier to complete and inter-rater differences will also decrease.
- d) Traceability in time. Ratings can be tracked and plotted as time-series data. This will allow following the development of a system in time based on the same criteria.

Furthermore, it also makes easier to identify areas of improvement for new development processes.

e) Marketing tool for HSI. The scorecard can be a good marketing tool for HSI providing the general audience more familiarity with the process.

Conclusions

Overall, preliminary comments on the scorecard after being used during the CEV technical reviews demonstrated that such HSI tools were instrumental in a systematic and structured assessment of the vehicle design. HSI tools can help track changes in systems and if used consistently at important phases of the lifecycle, they can provide information for cost-benefit estimations as well. Future work on the HSI scorecard will focus on using the tool for cost-benefit evaluations of early inclusion of human as a system within the vehicle design. Finally, different reporting formats will be developed to document the summary results for up and out communication.

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Authors' biography, addressing education, present employment, experience, recognition
for accomplishments, professional society memberships, not exceeding 150 words

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Anikó Sándor received her Ph.D. in Human-Computer Interaction and Cognitive Psychology from Rice University in 2007. She has been working as a researcher in the Johnson Space Center Usability Testing and Analysis Facility for more than 2 years, responsible for research on cursor control devices and user interface design issues. Before, she has worked as a usability specialist for Rice University and Reliant Energy. Dr. Sándor has experience in survey development, display design, heuristic evaluations and usability testing. She has co-authored several peer-reviewed publications, and has a user interface patent pending. She is a member of the Human Factors and Engineering Society.

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List of tables and figures

Figure 1. Screenshot of the first page of the scorecard. The reviewer can rate an item or specify reasons for not rating an item. There is a “Comments” section as well to allow adding more details.

HHS Scorecard - Williams, Daniel, McGuire, and Borker (2005)

HUMAN SYSTEMS INTEGRATION SCORE CARD

SA system name _____ Design phase N/A pre PDR PDR CDR SAR FRR

Subsystem _____ Reviewer _____

Type of review _____ Date _____

☒ Maturity expectations and assumptions _____

Area of Evaluation	Not rated a) not applicable b) design too immature c) need more information d) don't know e) other	Rating (1 - 5) 1 - unsatisfactory 2 - improvement needed 3 - meets expectations 4 - exceeds expectations 5 - exceptional	Comments (focus on vulnerabilities)
1 Human-Systems Integration Process			
1.1 The design team coordinated with stakeholders and other key personnel needed to be involved in the design.	a b c d e	1 2 3 4 5	
1.2 The design team incorporated inputs from human factors and other human-systems professionals.	a b c d e	1 2 3 4 5	
1.3 Conducted human-in-the-loop usability evaluation and integrated human-system performance testing for all conditions the system will be used (ground, EVA, etc).	a b c d e	1 2 3 4 5	
1.4 Performed task analysis to determine steps necessary to attain human goals for all conditions the system will be used (ground, EVA, etc).	a b c d e	1 2 3 4 5	
1.5 Performed human modeling/population analysis for all conditions the system will be used (ground, EVA, etc).	a b c d e	1 2 3 4 5	
1.6 The system was evaluated at different levels of integration (e.g. module level, concurrent use by multiple users) for all conditions the system will be used (ground, EVA, etc).	a b c d e	1 2 3 4 5	
1.7 There are limited or no deviations from requirements.	a b c d e	1 2 3 4 5	
1.8 Number of RDRs submitted and percentage of RDRs accepted.	a b c d e	1 2 3 4 5	

Figure 2. A possible visualization of average hypothetical ratings of a system on a review.

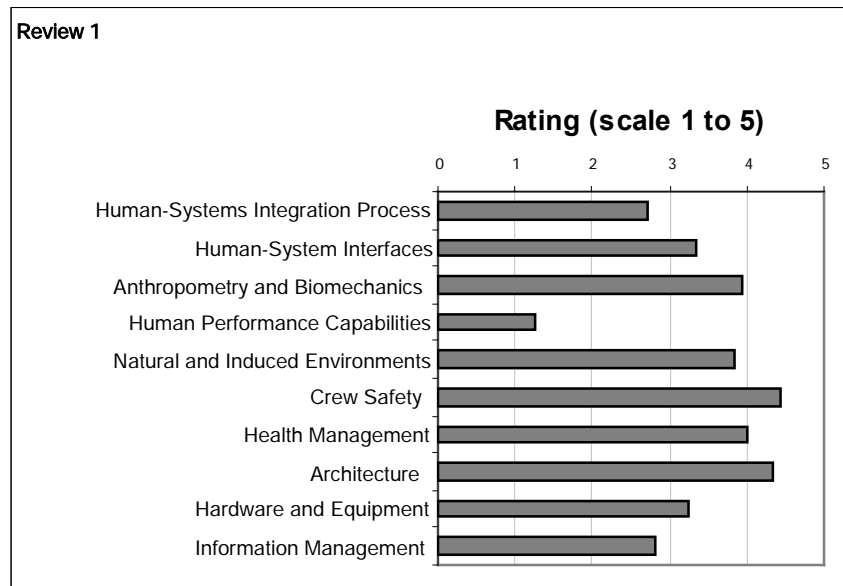


Figure 3. Graph showing hypothetical results from five reviews for the same system that were conducted in different phases of the lifecycle. This allows for an overview of system development.

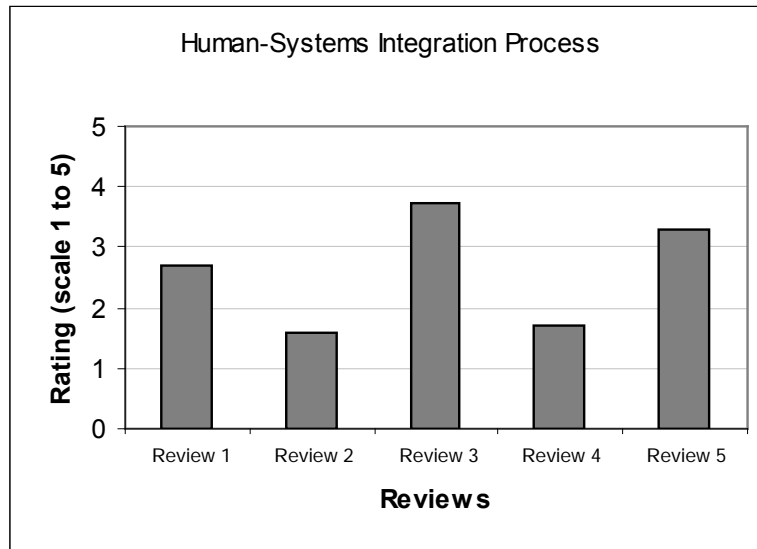


Table 1

Hypothetical ratings of a system across all areas in five reviews.

	Areas	Review 1	Review 2	Review 3	Review 4	Review 5
1	Human-Systems Integration Process	2.70	1.60	3.75	1.70	3.30
2	Human-System Interfaces	3.35	2.25	3.20	2.80	3.90
3	Anthropometry and Biomechanics	3.95	4.00	4.30	2.35	1.65
4	Human Performance Capabilities	1.25	2.70	1.65	2.80	2.85
5	Natural and Induced Environments	3.85	2.75	3.75	4.30	3.25
6	Crew Safety	4.45	3.90	4.85	1.75	4.35
7	Health Management	4.00	3.35	2.25	3.80	3.65
8	Architecture	4.35	3.45	1.50	3.45	2.85
9	Hardware and Equipment	3.25	3.10	2.70	3.90	4.30
10	Information Management	2.80	3.65	3.35	2.80	2.80